

Modification of wood wettability by plasma and corona treatments

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Abstract

The durability of an outdoor wood-coating system is low, especially when the coating is a stain. The most important degradations come from the dimensional variations of wood which strain the coating and lead to its cracking. Thus the service life of a wood-coating system can be increased through different routes:

- Improvement of the coating flexibility: it can be obtained by decreasing the glass transition temperature (T_g) below the temperature of use. But in this case the coating is more sensitive to water
- Dimensional stabilization of wood: thermal and chemical treatments (acetylation) are efficient but most of them decrease the wettability of the wood surface and therefore the adhesion of the coating is no more guaranteed.

Surface treatments are convenient either to improve wettability and therefore coating adhesion or to decrease wettability in order to provide an extra protection. That is why plasma and corona treatment have been applied to wood in two ways:

- The first way consists in improving the wettability of wood surface to increase the coating adhesion especially after a thermal treatment. First experiments consist in selecting treatment parameters (type of gas, treatment duration, power) leading to better surface characteristics of wood, before and after thermal treatments. Plasma and corona treatments are effective to improve the wettability of wood but no improvement in the coating adhesion has been observed.
- The second way consists in decreasing the wettability so that the surface becomes waterproof. Some tests have been performed to deposit thin films (based on ethylene or fluorine) by plasma or corona treatments. This kind of deposits can be considered either on bare wood or on coated wood with a low T_g stain, that is to say, a stain whose sensitivity against water will be solved because of this kind of films. This is the aim of an on-going research programme. © 2000 Elsevier Science Ltd. All rights reserved.

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1. Introduction

In France wood protection outdoors is generally achieved by staining. This kind of product has a low durability especially due to the dimensional variations of wood which strain the coating and lead to its cracking. A solution to improve the durability of the wood coating system is to increase the stain flexibility, but this often leads to a more important sensitivity to water and to degradations. Stabilising the dimensional variations of

wood before applying a coating can be another solution. Chemical and thermal treatments [1–3] are efficient to reduce these variations but few data about the compatibility of these treatments and coatings are available in the literature. It is well known that thermal treatment reduces the wood wettability [4].

Plasma and corona discharge treatments (CDT) are commonly used on polymer films. It is generally accepted that these treatments modify the substrate polymer surface properties like wettability and adhesion. The principal fields of application are adhesive bonding, printing and extrusion coating and transposition to wood is expected with a good result. Plasma is the fourth state of

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the matter, generated by a discharge induced in a partial vacuum. It is an excited gas that consists of atoms, ions, molecules, free radicals, electrons and metastable species. Their interactions with the solid surface placed in the plasma lead to the desired surface properties depending on the nature of the gas used.

The effects of air or oxygen plasma and CDT on polymer films are well known. Indeed, the chemical surface modification induced on PE and PP is widely reported [5–11]. The first step is the formation of radicals on the top layer of the polymer surface which can react with each other to cause cross-linking or branching (polymerisation), or with O_2 molecule and O atomic. The surface is oxidised. The wettability is increased and is often correlated to this oxidation. The most important application is the adhesion of resins like epoxy and PU.

The influence of the treatment parameters (time, power, frequency) is not negligible. The most important parameters are time and power. The results on the previous properties induced by plasma and CDT are different according to the authors [12,9,13] and are dependent on the geometry of the electrode and the frequency, not common for each. Ageing of the treatment on the adhesion property is also studied [14]. A new field of application is to improve adhesive bonding of wood [15,16].

No recent approach was made on wood to improve varnish adhesion and durability of exterior wood-coating system. The aim of this article is to study the influence of thermal treatments and plasma or CDT on wood wettability and wood finishing, check the application of plasma or CDT on thermal wood and, lastly try to find a solution to protect the wood without the application of a finishing.

2. Influence of thermal treatment on wood wettability

Wood wettability has been characterised by contact angle measurements using the two liquids phase method: Wood is dipped in octane and contact angle of water droplets is recorded along the grain. In this direction contact angle is not influenced by the wood roughness. Ten droplets of 10 μ l are used to calculate a mean contact angle. The influence of thermal treatments appears in Fig. 1. The higher the temperature, the lower the wettability. On wood samples treated at 100 or 160°C, a loss in adhesion of coating (waterborne and solventborne) has been observed due to the decrease in wettability.

The wood extractable compounds are responsible for the weak wettability and the weak adhesion after thermal treatment. They migrate to the surface and form a weak boundary layer, thus preventing penetration of the coating or the glue [17]. High temperatures change the macromolecular structure of the wood compounds. Hemicelluloses are the most sensitive compounds to temperature. Their decomposition at 120–130°C leads to the lignin degradation [18]. Then, aldehyde and acids are formed. The thermal stability depends on the considered wood compound [19]. The wood shrinks and some pores, filled with extractable compounds are formed. Increasing the temperature accelerates the degradation reactions.

The wood is stabilised by thermal treatment, but the finishing adhesion is weak. A satisfactory level of wettability must be acquired before the finishing application, without affecting the bulk properties. The idea is thus to restore a satisfactory level of wettability. That is why plasma and corona treatments have been studied.

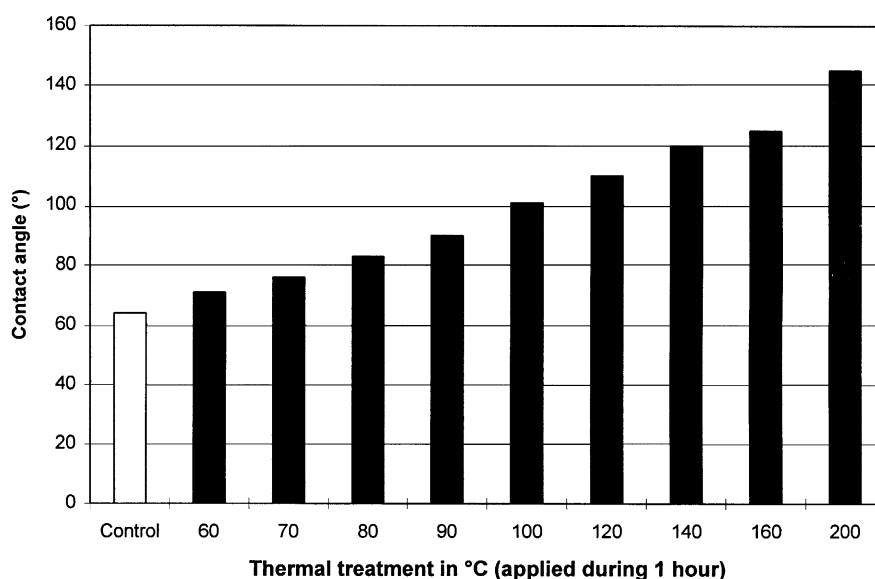


Fig. 1. Influence of thermal treatment on Fir wettability.

3. Improvement of wood wettability

3.1. Plasma treatment of wood

Plasma treatment has been found to be very effective in modifying the surface properties of various polymers such as their wetting behaviour and adhesion characteristics.

This treatment should be able to improve the surface properties of wood especially in the case of low wettability due to a chemical or thermal treatment.

Plasma treatments have been carried out by the Institut Textile de France (Institute for the French textile industries) in Lyons. Then they have been characterised by contact angles measurements at the Centre Technique du Bois et de l'Ameublement (Technical centre for wood and furniture).

First experiments consisted in determining treatment parameters (type of gas, treatment duration, power ...) leading to better surface characteristics of wood. The wood species used for these experiments was fir.

3.1.1. Influence of treatment power

Oxygen plasma was applied to wood with a power from 400 to 1200 W. The treatment time was 5 min, the pressure 0.08 mbar, and the distance from the samples to the plasma source 44 cm.

After treatment, samples were placed in an air conditioned room (20°C and 65% of relative humidity) and sheltered from light. Contact angles were measured 15 d after the treatments. Results are given in Fig. 2. An important decrease in the contact angle is observed due to the plasma treatment: wood is oxidised like synthetic polymers. Values are close for the different treatment

power. For the next experiments, a power of 900 W was chosen,

3.1.2. Influence of treatment time

Oxygen plasma was applied to wood with a treatment time varying from 1 to 30 min. The power was set to 900 W, the pressure to 0.08 mbar and the distance from the samples to the plasma source to 44 cm. Contact angles were measured 15 d after treatment. Results are reported in Fig. 3. The longer the treatment time the lower the contact angle. This becomes stable from a treatment time of 5 min. That is why next plasma experiments have been carried out with a treatment time of 5 min.

3.1.3. Influence of the distance from the samples to the plasma source

Oxygen plasma was applied to wood samples placed at distance of 28–44 cm from the plasma source. The time treatment was set to 5 mins, the pressure to 0.08 mbar and the power to 900 W.

Contact angles were measured 15 d after the treatments. Results are reported in Fig. 4. The wettability decreases as the distance between samples and the plasma source increases. Results are nearly the same for the distances of 28 and 44 cm. Next experiments were conducted with a distance of 44 cm.

3.1.4. Influence of the type of gas

Different gases have been tested alone and blended with oxygen. The treatment time was 5 min, the power 900 W, the pressure 0.08 mbar, and the distance from the samples to the plasma source was equal to 44 cm. Contact angles were measured one week after the treatments.

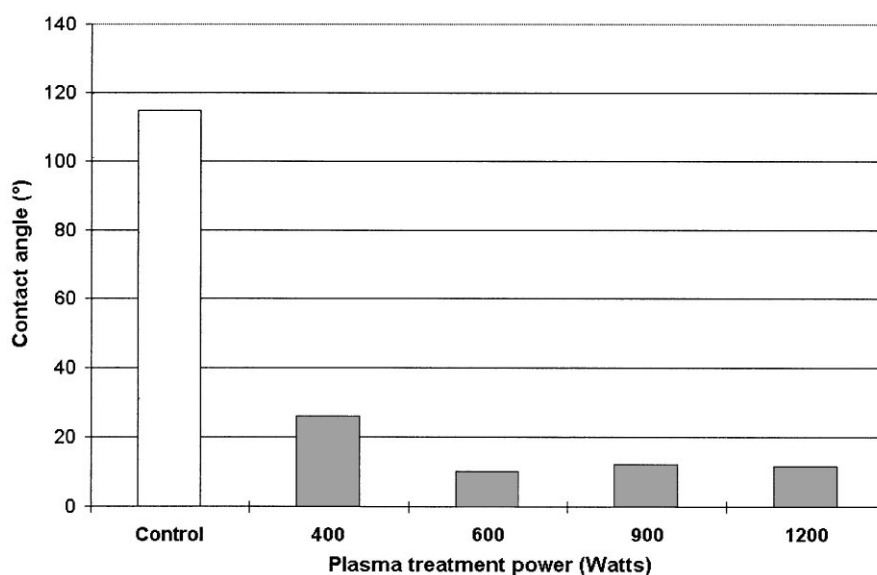


Fig. 2. Influence of the treatment power on fir wettability.

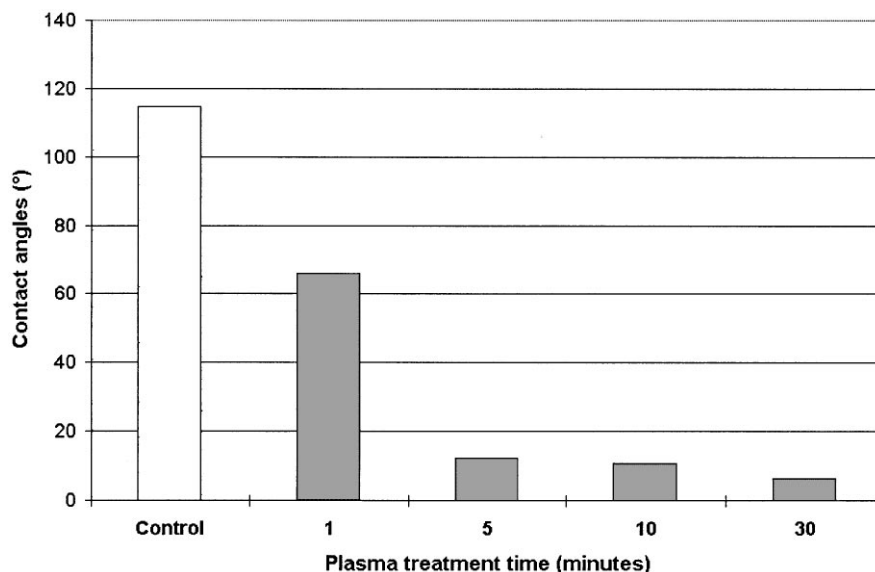


Fig. 3. Influence of the plasma treatment time on fir wettability.

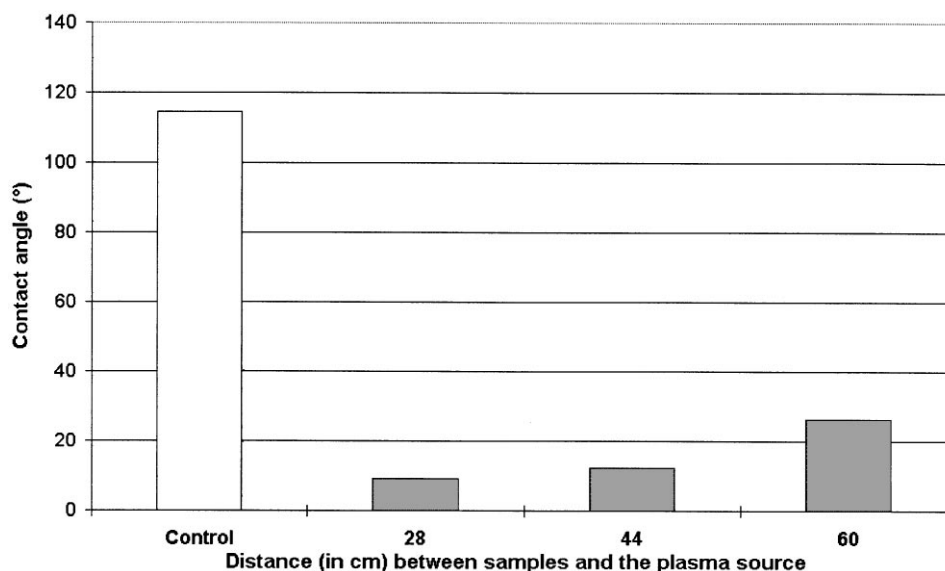


Fig. 4. Influence of the distance between samples and the plasma source on fir wettability.

Results appear in Fig. 5. Oxygen, nitrogen, carbon dioxide give good results whereas ammonia leads to an increase in contact angles. Blended with oxygen, argon and nitrogen produce low contact angles close to those obtained with oxygen used alone. Adding O_2 to NH_3 allows an increase in the surface characteristics compared to NH_3 alone.

3.1.5. Stability of plasma treatments

These previous results were completed with contact angle measurements two weeks after treatments in order to establish the plasma treatment stability according to the type of gas. Results are reported in Fig. 6.

Fig. 6 shows that oxygen and nitrogen plasma have an interesting stability. Air plasma leads to a better wettability but is less stable.

3.2. Plasma treatment on torrefied wood

Surface properties are modified by high temperatures as shown previously (see Fig. 1). Thus it should be interesting to apply a plasma treatment on such modified wood in order to restore interesting wettability. That is why the influence of plasma treatment on torrefied wood has been studied. Samples of curupixa (Brazilian wood) were torrefied at 230°C for 60 min.

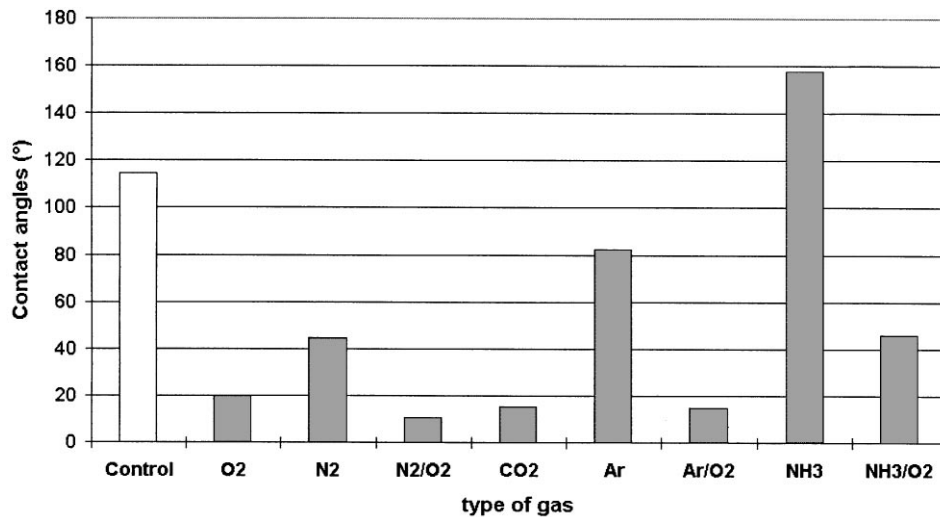


Fig. 5. Influence of the type of gas on fir wettability.

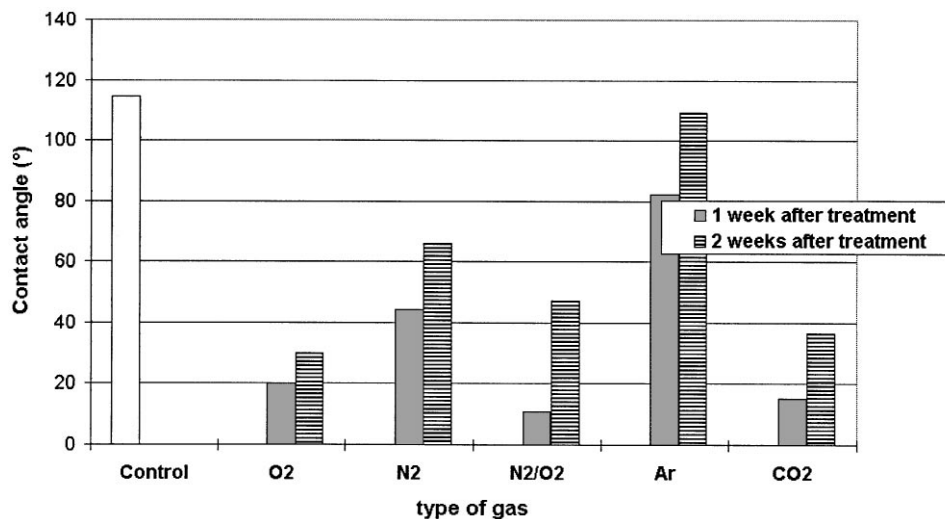


Fig. 6. Stability of plasma treatments.

Before plasma treatments, contact angles were measured. Results are shown in Fig. 7. Torrefaction leads to an important decrease in wettability. Then an air plasma was applied to curupixa samples with treatment parameters previously selected. Fig. 7 shows contact angles measured 7 and 15 d after the plasma treatment.

The effect of plasma treatment is more important on torrefied curupixa than on the control (non-torrefied). It seems that the efficiency of the plasma treatment depends on the initial level of surface wettability. In these experiments, plasma treatments are very stable and it seems that the stability depends on the wood species treated.

3.3. Corona treatment

Corona discharge (CDT) is produced at atmospheric pressure and is an alternative to plasma treatment. CDT is mainly used as an activation treatment of polymers and fibres. As for plasma treatments, corona parameters have been studied on wood in order to obtain better surface characteristics. Contact angle measurements have been carried out with glycerol. The wood species was oak. Treatments and characterisation have been made at the University Henri Poincaré of Nancy.

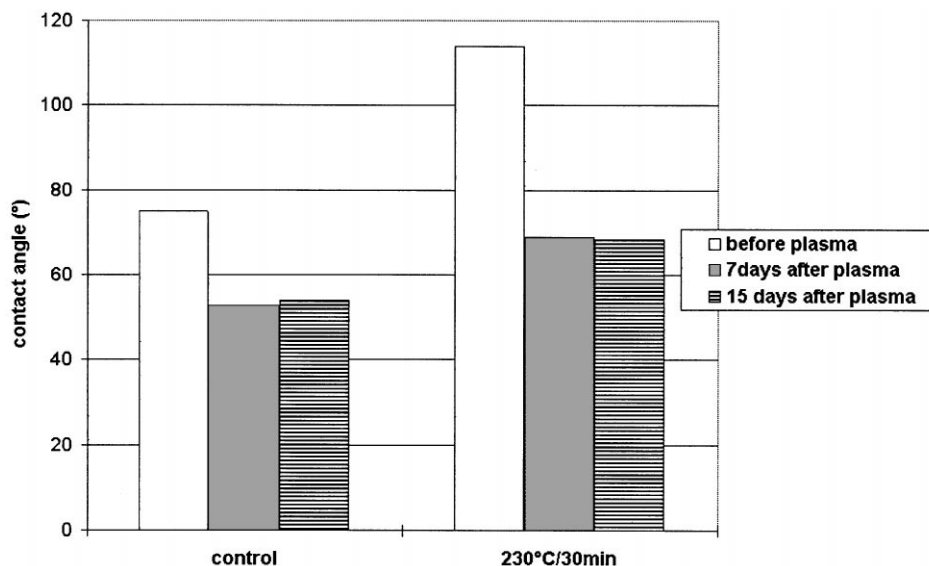


Fig. 7. Plasma treatment of torrefied wood.

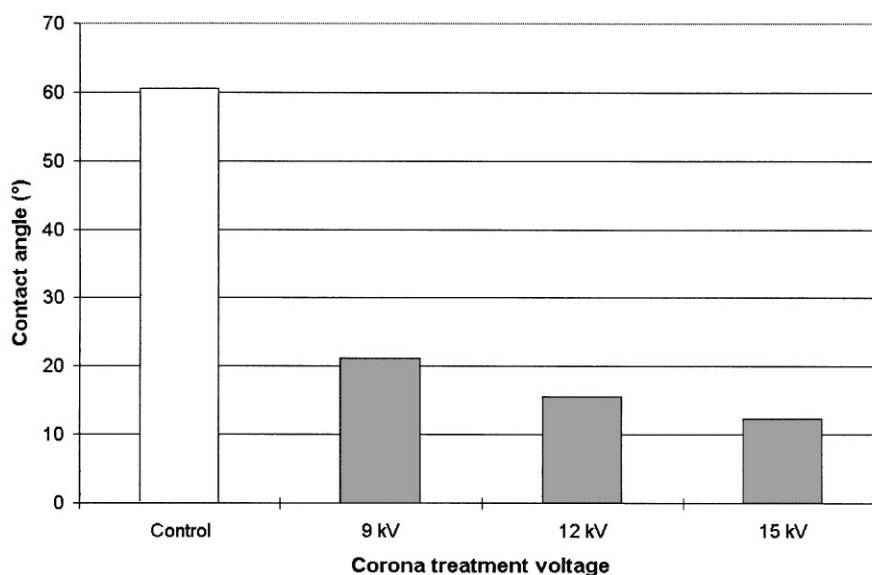


Fig. 8. Influence of the corona voltage on oak wettability.

3.3.1. Influence of the treatment voltage

Fig. 8 shows the results obtained for air corona treatment applied during 5 min. As for plasma treatment, the higher the corona voltage, the lower the contact angle.

3.3.2. Influence of the treatment time

An air corona treatment has been applied to wood at 9 kV for various treatment times. Results are shown in Fig. 9. As previously, the longer the treatment the higher the increase in wettability.

3.4. Comparison of plasma and corona treatments

Plasma and corona treatments have not been made in the same conditions: wood species, liquid and method for the wettability characterisation are different. However, the efficiency of both treatments is compared by calculating the wettability improvement (in percent) due to the treatment. This has been made for two gases: air and nitrogen. Results are shown in Fig. 10. Even with the highest voltage (15 kV), corona is less efficient than plasma to improve wood wettability.

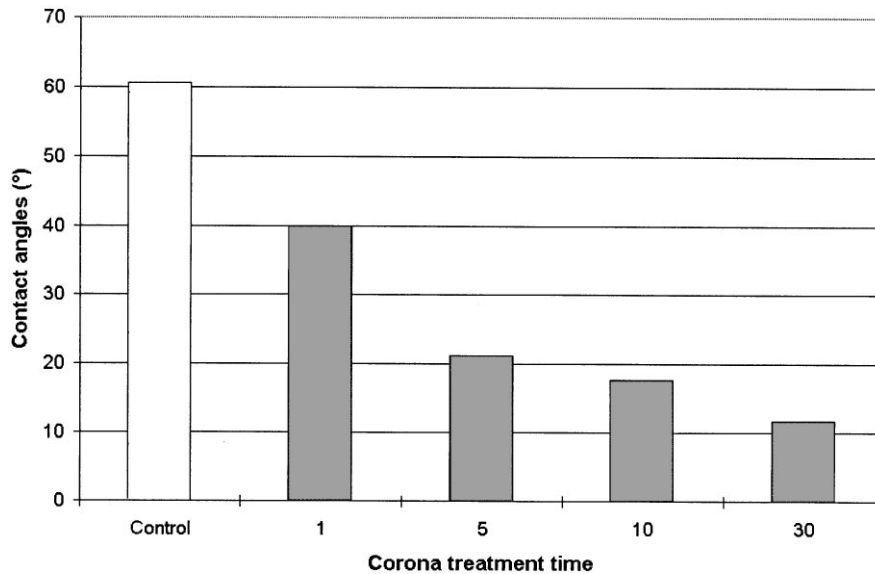


Fig. 9. Influence of the corona treatment time (minutes) on oak wettability.

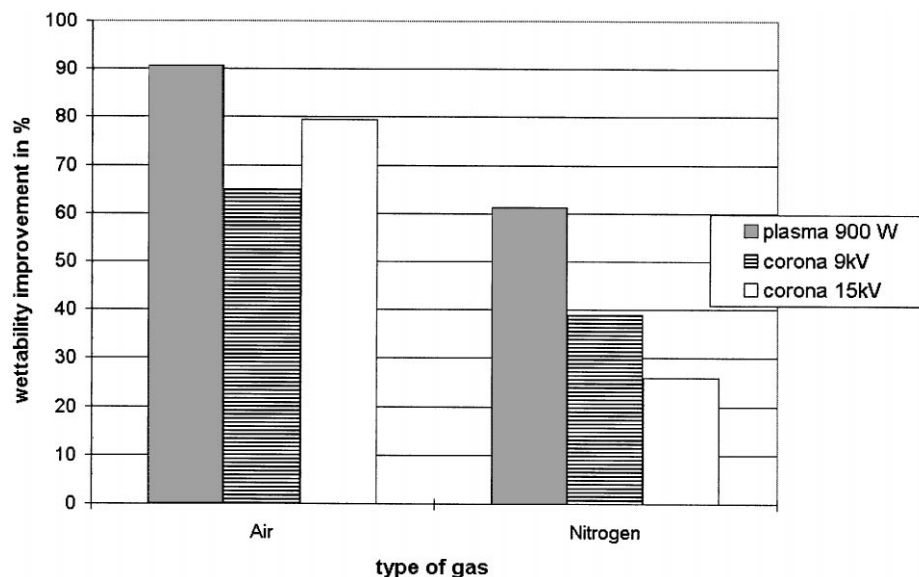


Fig. 10. Comparison plasma–corona.

3.5. Behaviour of coatings on plasma-treated wood

Two wood species have been used for these tests: sylvestris pine and lauan-meranti. Some samples of lauan-meranti have been torrefied.

Three plasma treatments have been applied: oxygen, carbon dioxide, air. Two coating systems, one solvent based and one water based, have been applied on these samples as follows:

solvent-based system: 1 coat of primer (36% solid content, alkyd resin)
2 coats of finishing (50% solid content, alkyd resin)

water-based system: 1 coat of primer (30% solid content, alkyd-acrylic resin)
2 coats of finishing (43% solid content, acrylic resin)

They were applied by brush, one week after plasma treatment. After 15 d at 20°C and 65% of relative humidity, samples have been exposed to artificial weathering on a Gardner wheel.

The adhesion was measured by pulling off a self adhesive tape place on the coating surface. Before and after six weeks of artificial weathering, the adhesion was good since no coating was pulled off by the adhesive.

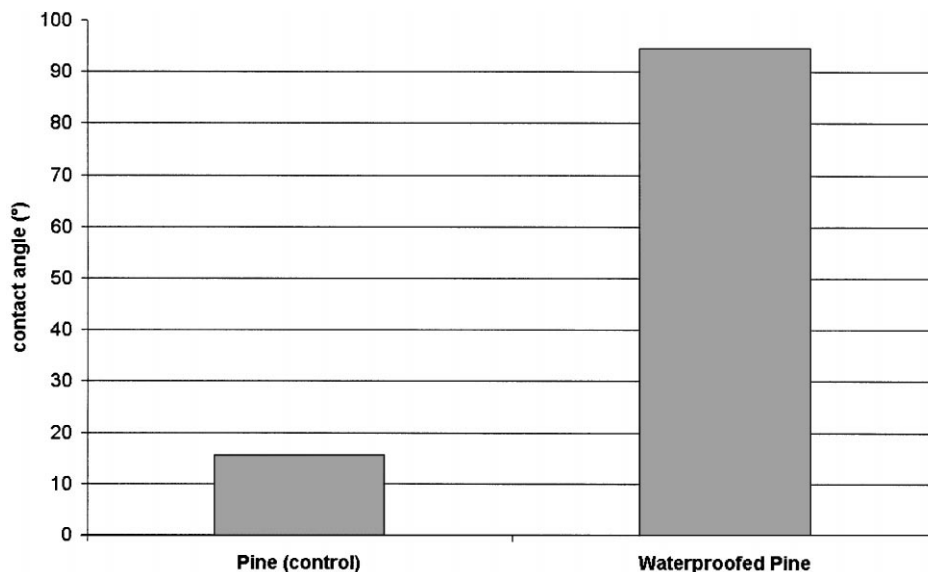


Fig. 11. Wood waterproofing with plasma treatment.

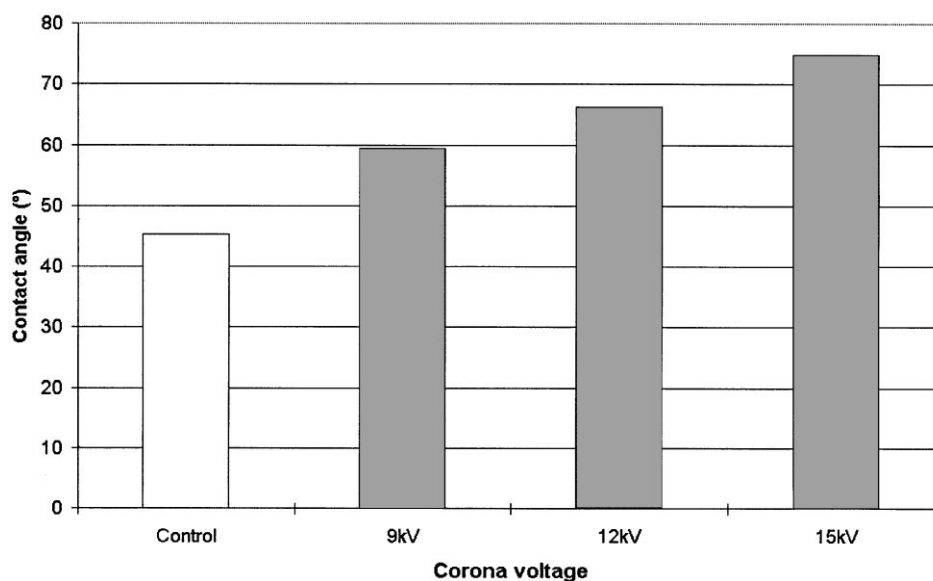


Fig. 12. Wood waterproofing with corona treatment.

After six weeks of weathering, a beginning of cracking and flaking was observed on coatings applied to torrefied wood, with and without plasma treatment. The lower adhesion compared to non-torrefied wood is probably due to torrefaction.

It was not possible to observe any improvement in the coating behaviour due to the plasma treatment. The effect of this treatment was probably concealed by the coating characteristics: the performances of the products were probably too good. Further experiments should be carried out on coatings with simplified formulas. Natural weathering test are in progress and will give further

information about the influence of plasma treatments on wood coatings.

4. Wood waterproofing by plasma and corona

Plasma and corona treatments are effective to improve wood wettability but can also be used to decrease it in order to waterproof wood. This can be a new means of protection for wood against water and thus for wood used outdoors.

4.1. Wood waterproofing by plasma treatment

A blend of gases ($\text{CF}_4 + \text{C}_3\text{F}_6$) has been introduced in the reactor. Pine samples have been then treated for 15 min with a power of 900 W. Results of contact angle measurements (with water) are presented in Fig. 11.

An important decrease in wettability is observed leading to good waterproofing.

4.2. Wood waterproofing by corona treatment

Corona treatments based on ethylene gas have been applied to oak with various voltage. The flow meter was 1 l/min and the treatment time 5 min. Results are reported in Fig. 12. The decrease in wettability can also be obtained with corona treatments but is less important than for plasma treatments.

In further steps, the behaviour of these kind of treatments after weathering will be studied.

5. Conclusion

The aim of this work was to find solutions to improve the durability of coatings.

Stabilising dimensional variations of wood should be a means of improvement. However, our experiments have shown that available treatments (thermal or chemical) lead to poor surface characteristics. A decrease in the wood wettability is noticed and the adhesion of coatings is not satisfactory.

That is why plasma and corona treatments have been studied on wood in order to restore increasing surface properties. Results have shown that these technologies are efficient on wood. Treatment parameters leading to better surface properties have been defined.

However, it has not been possible to prove the link between a good wood wettability and a better coating

adhesion, and further experiments are necessary to clarify the effect of plasma treatments on the coating durability.

These technologies can also be used to waterproof wood and form new kind of films at the wood surface. It is now necessary to study the ageing of these new deposits.

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